

Combinatorial
Methods Group

Combinatorial Investigations of Polymer Adhesion

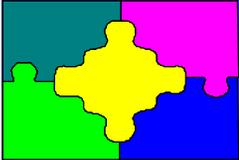
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Combinatorial Investigations of Polymer Adhesion

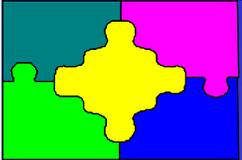
Motivation

- Adhesion influences numerous industries
- Myriad of variables control adhesion
- Existing techniques have disadvantages

- Surface Energy
- Molecular Weight
- Time
- Temperature
- Humidity
- Roughness
- Geometry

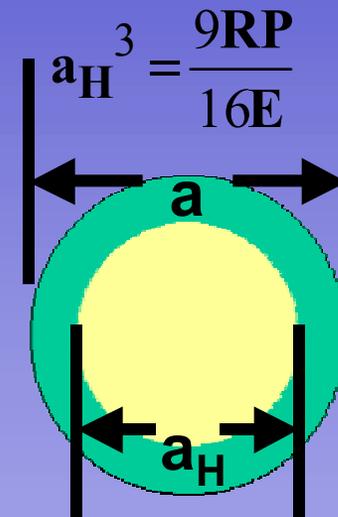
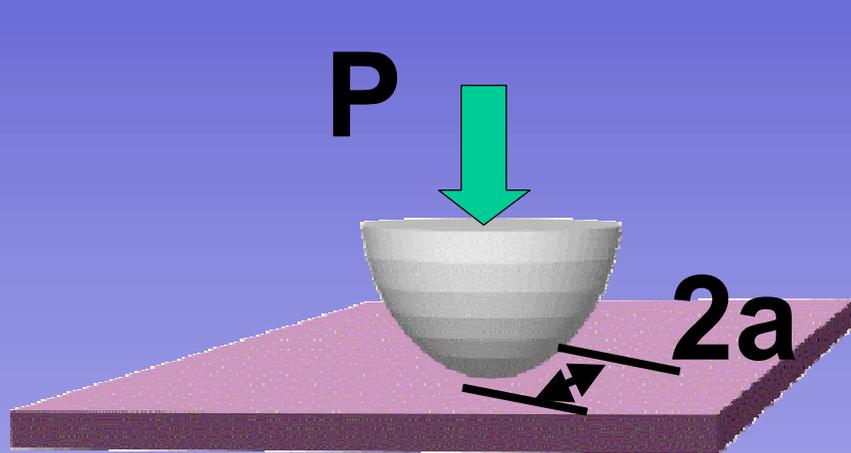
Objective

- Develop methodology for quantitative high-throughput measurements of adhesive strength of polymer interfaces



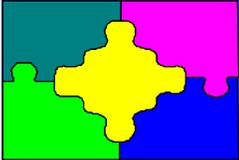
How do we study polymer adhesion?

JOHNSON, KENDALL, & ROBERTS (JKR)



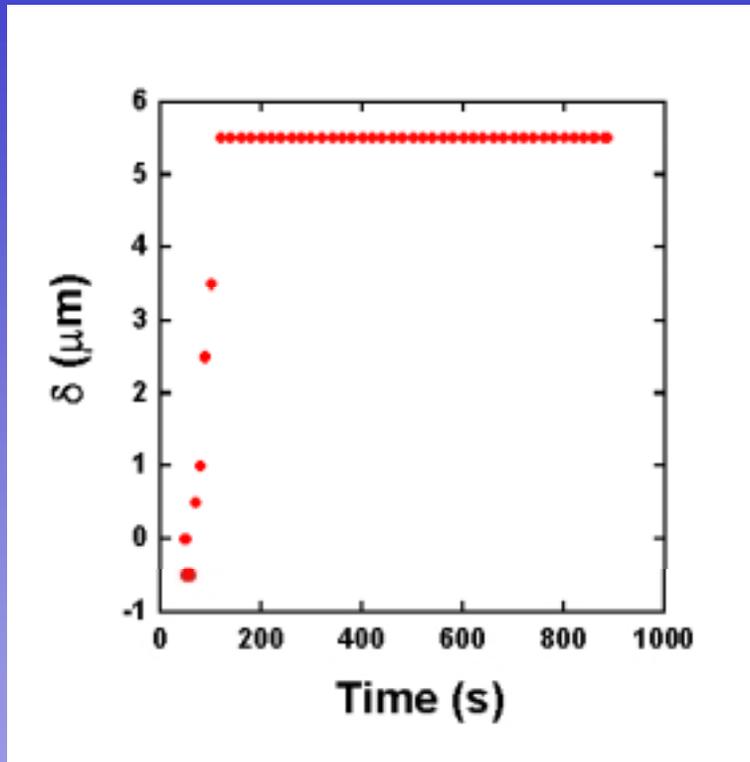
$$a^3 = \frac{9R}{16E} \left[P + 3\pi GR + \sqrt{6GRP + (3\pi GR)^2} \right]$$





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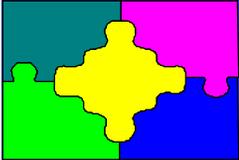
Why choose JKR?



PDMS contacting glass

Classical Use:

- Fundamental studies of adhesion of soft polymers
- Limited to elastic materials and geometries where $a \ll h, R$



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Why choose JKR?

Recent Developments have allowed JKR to be applied to a wide range of issues

Finite-Size Corrections (for $a > h$)

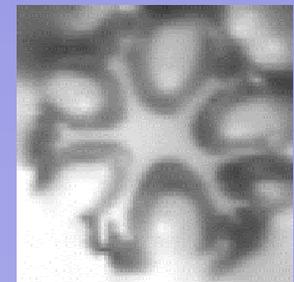
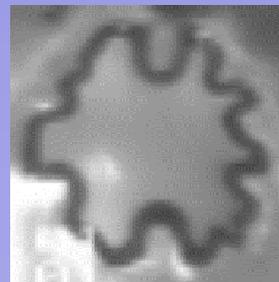
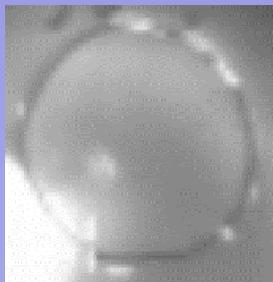
Shull, K.R., et al, *Macromol. Chem. Phys.*, 1998, **199**, 489-511.

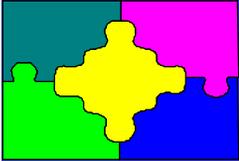
Crosby, A.J. et al, *Journal of Applied Physics*, 2001, **88**, 2956-2966.

Viscoelasticity Corrections

Lin, Y.Y., et al, *Journal of Applied Physics*, 1999, **32**, 2250-2260.

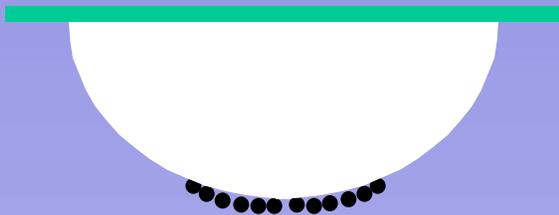
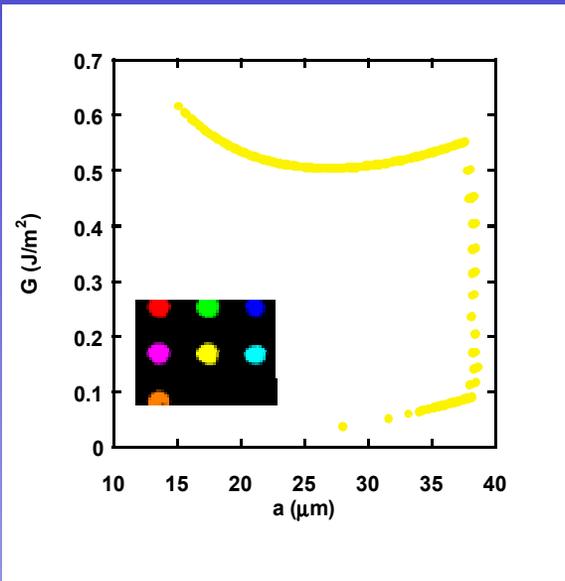
Johnson, K.L., ACS publication, 2000.

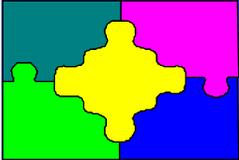




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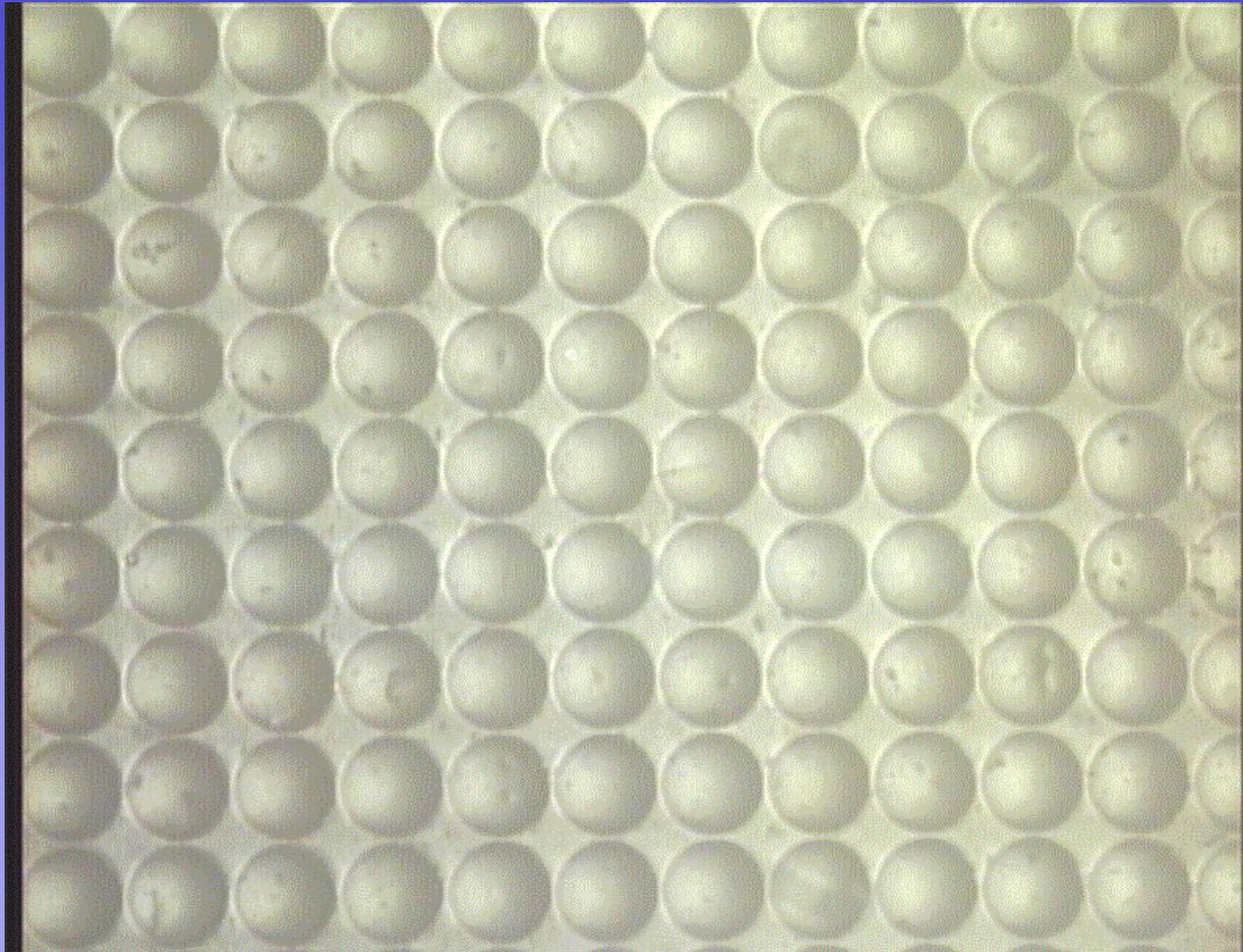
What about an array of lenses?

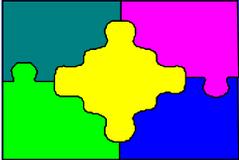




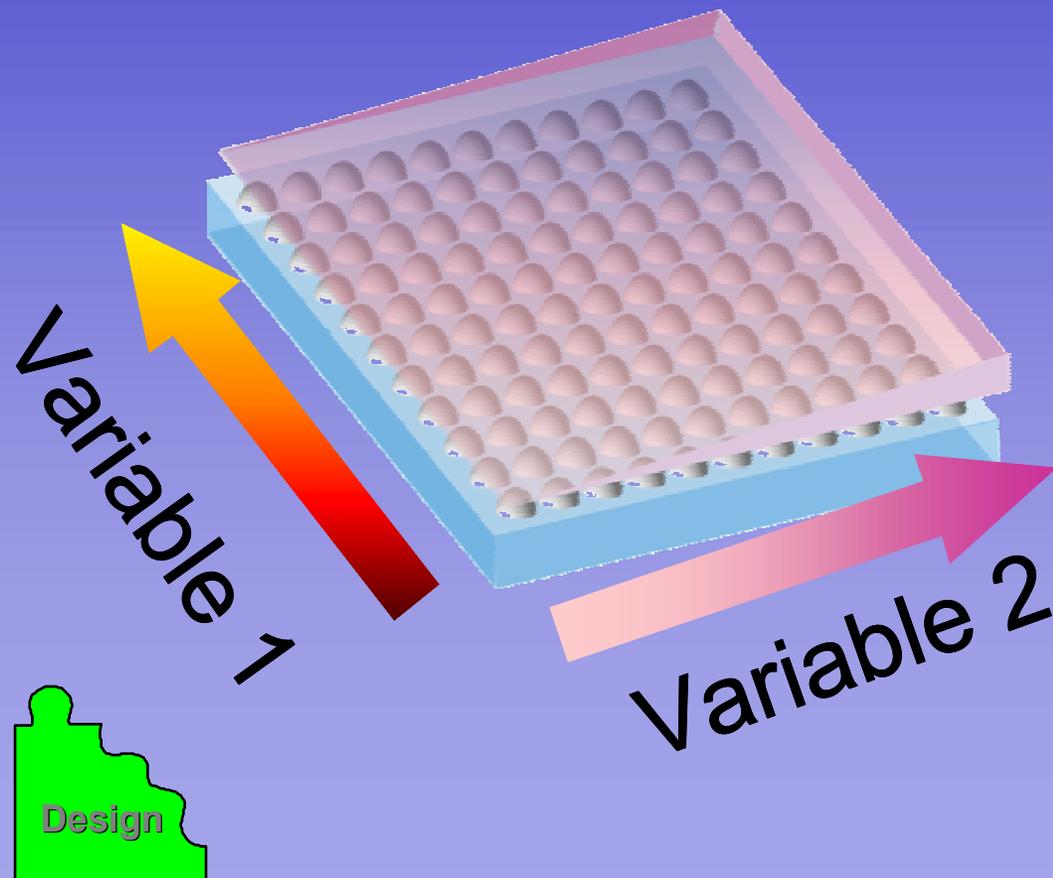
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Why not more?



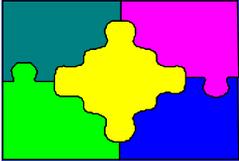


How do we design a *combinatorial* JKR test?



- Measure a , δ
- Determine \mathcal{G}

- Possible Variables:
 - Temperature
 - Thickness
 - Strain
 - Surface Energy

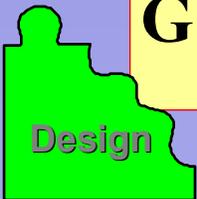
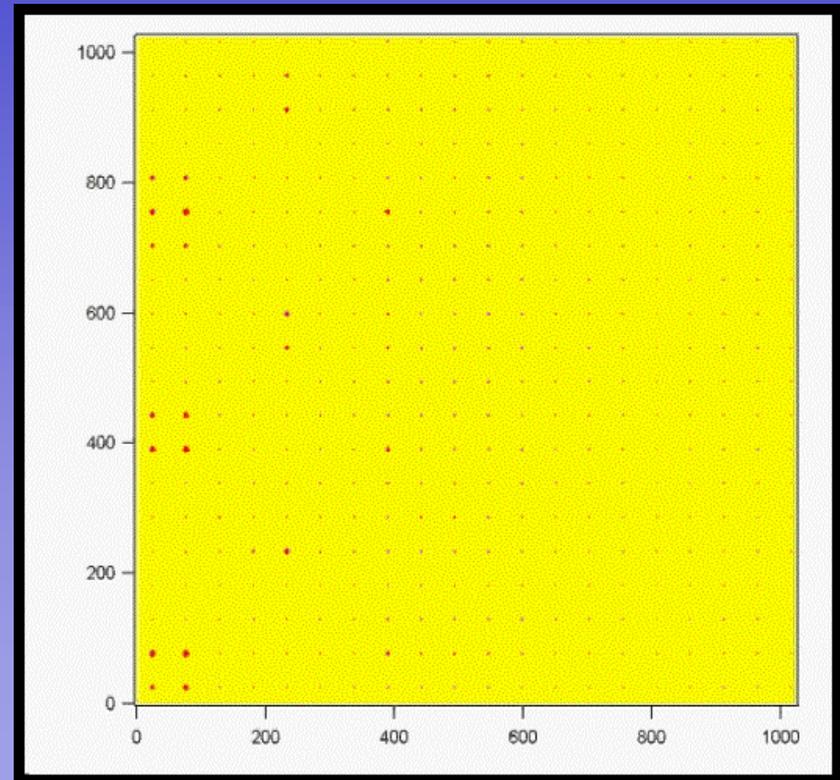


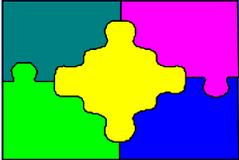
How do we calculate G ?

$$a^3 = \frac{9R}{16E} \left[P + 3\pi GR + \sqrt{6GRP + (3\pi GR)^2} \right]$$

$$C = \frac{3}{8Ea} = \frac{d\delta}{dP} = \frac{\delta' - \delta}{P' - P}$$

$$G = \frac{2E(\delta' - \delta)^2}{3\pi a} \cdot f_\delta(a, h)$$

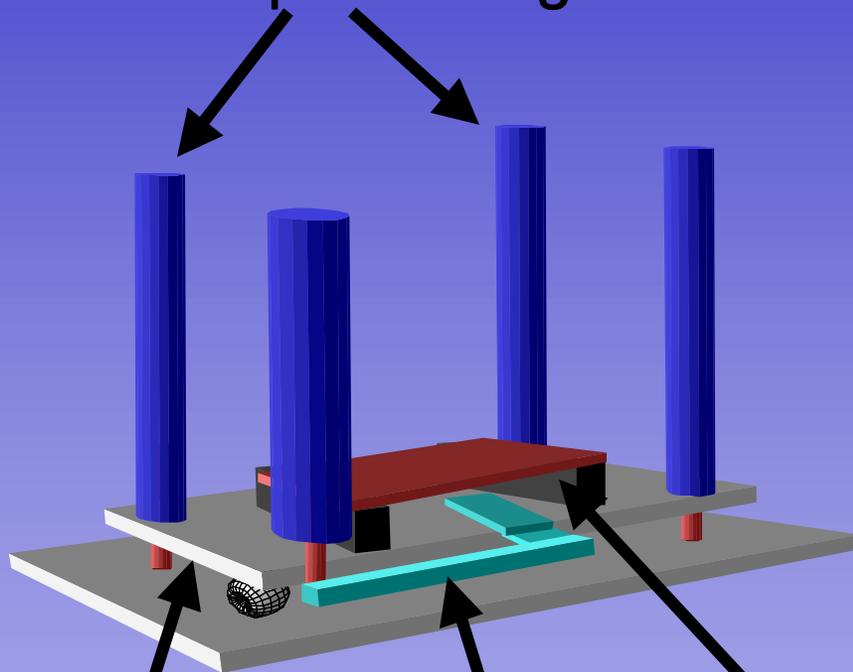




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How do we control contact?

Nanopositioning Actuators



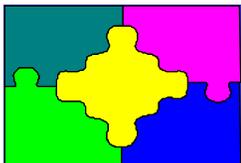
Tip/Tilt Stage

Thermal Gradient Stage

Multilens Probe Holder



Programmable X-Y Stage

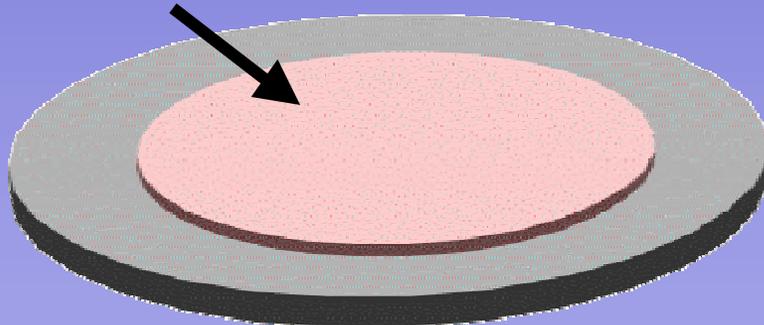


What problem to consider first?

- The Adhesion of Glassy Polymers to Elastomers
- Specifically, PS to PDMS

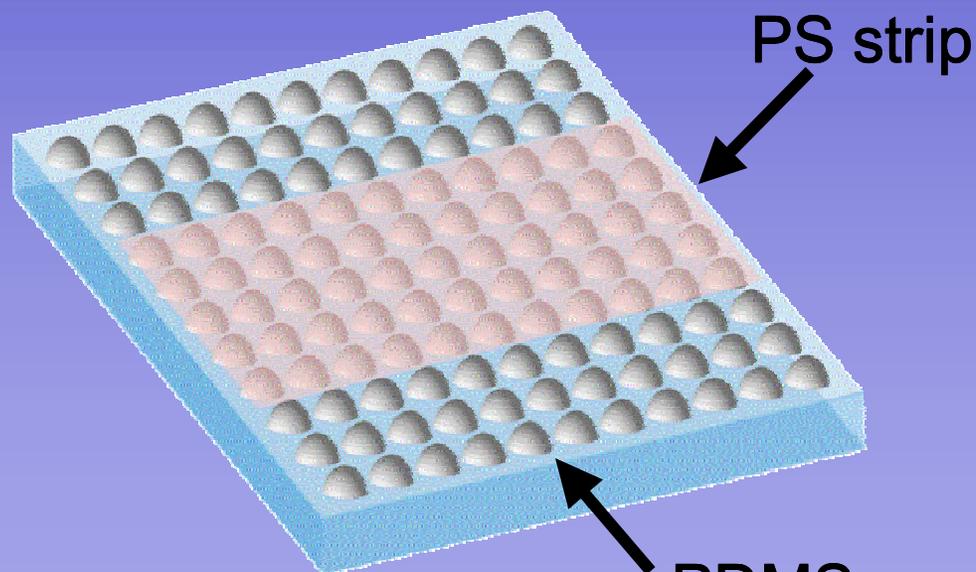
Our Libraries:

PS film
 $h = 30 \text{ nm}$

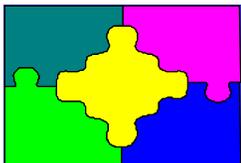


Library
Generation

Si substrate

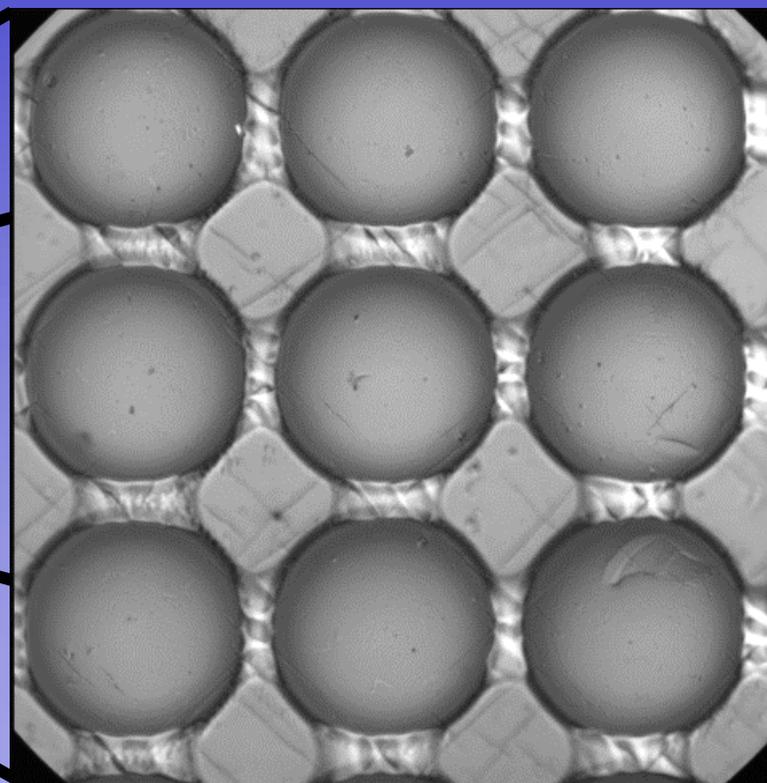
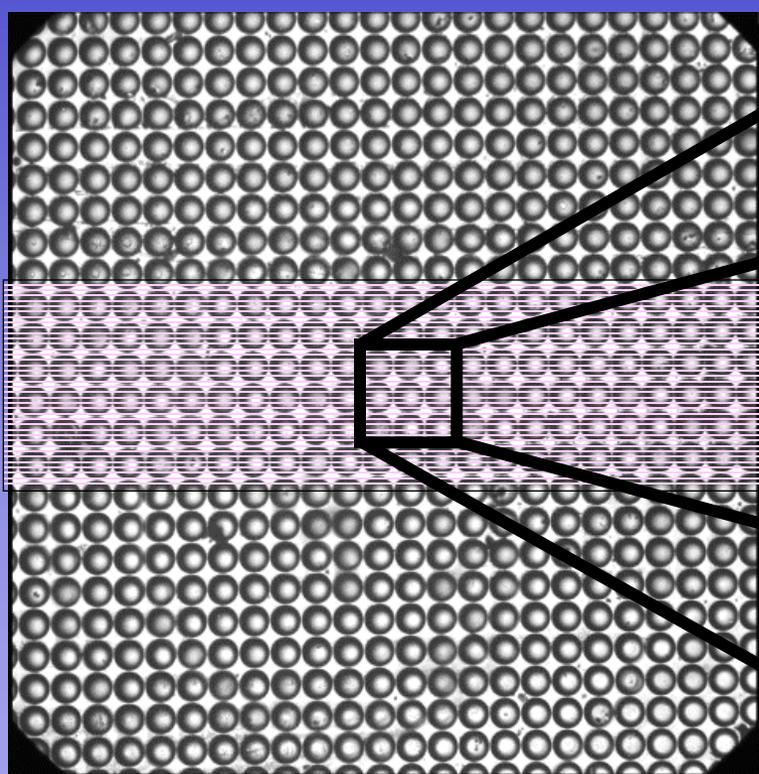


PDMS



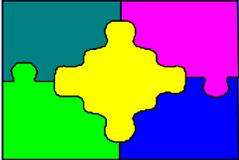
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What do our libraries look like?



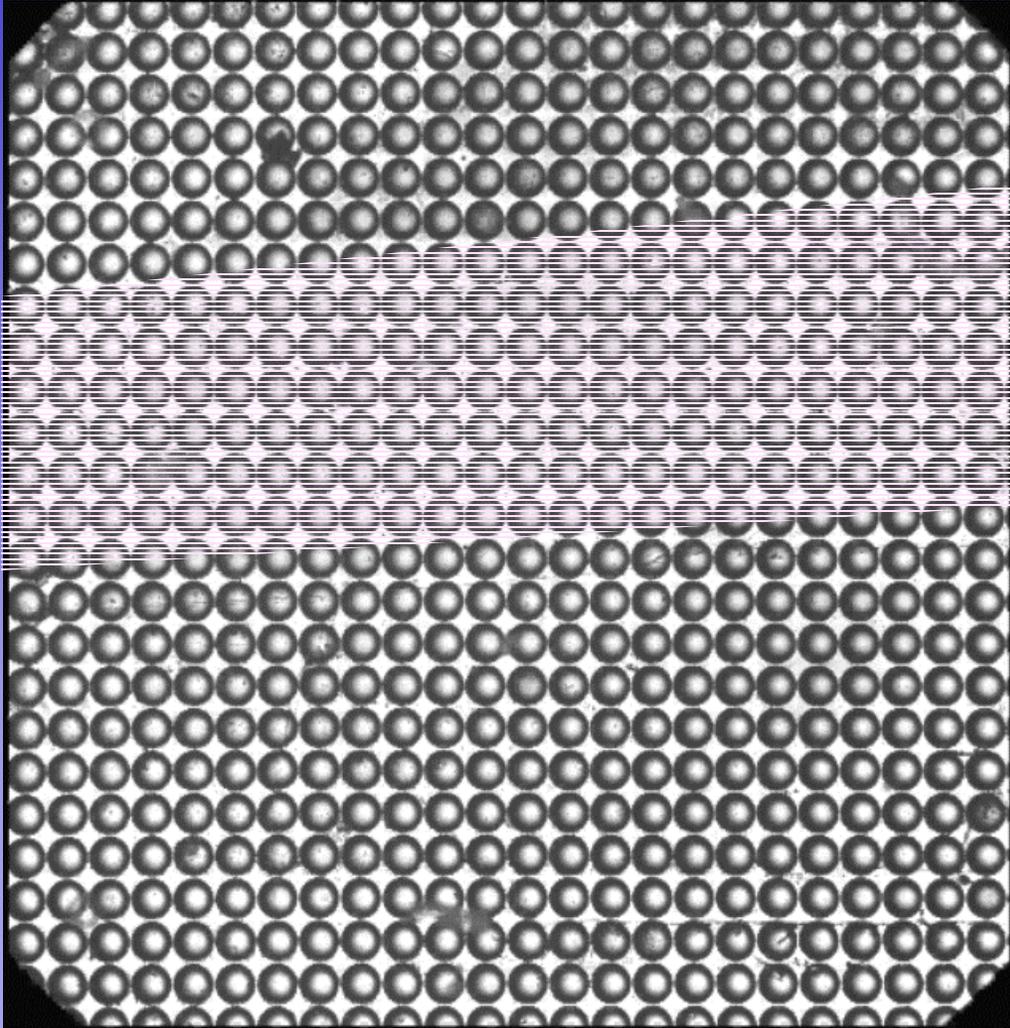
100 μm

Library
Generation



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What do we observe?



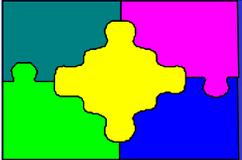
Conditions:

$$d\delta/dt = 1 \mu\text{m/s}$$

$$h_{\text{PS strip}} = 30 \text{ nm}$$

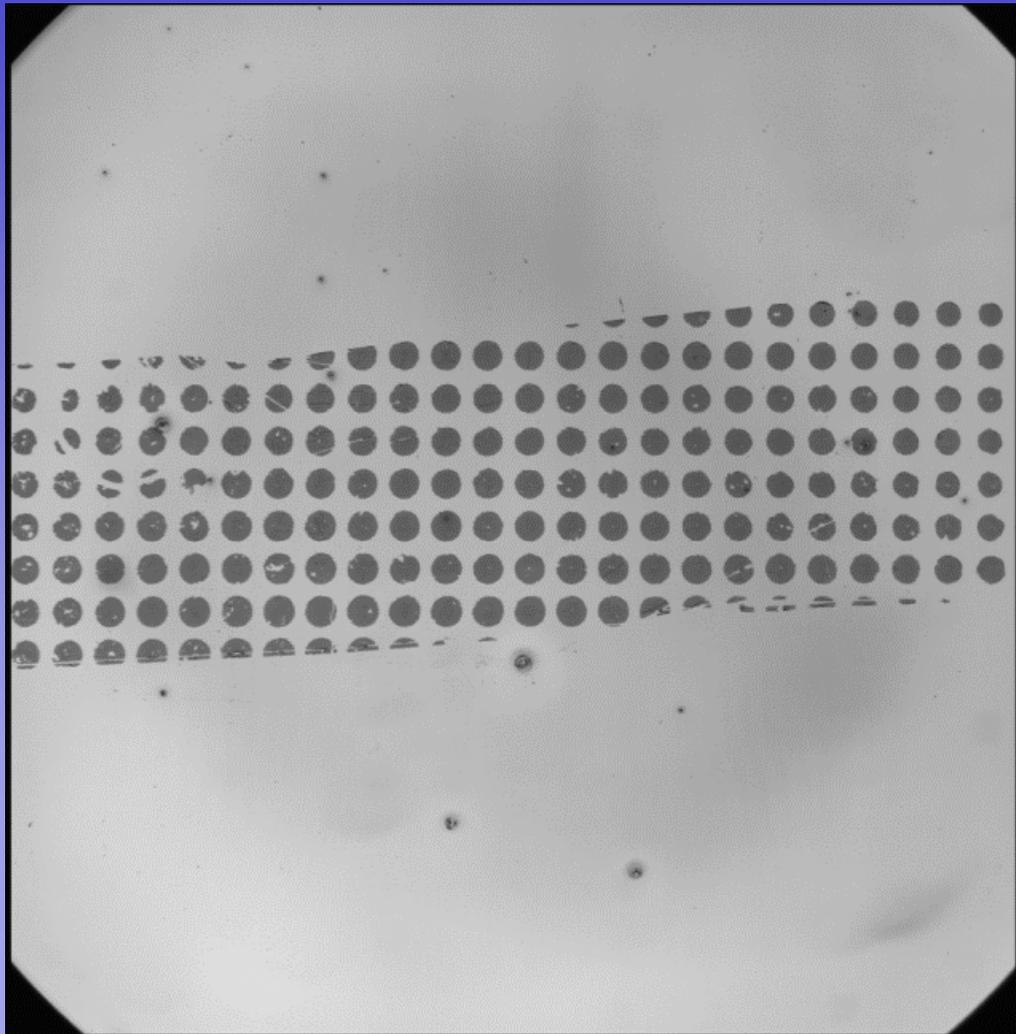
$$\text{Temperature} = 25^\circ\text{C}$$

Library
Evaluation



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What happens at elevated temperature?



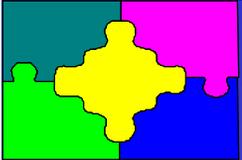
Conditions:

$$d\delta/dt = 1 \mu\text{m/s}$$

$$h_{\text{PS strip}} = 30 \text{ nm}$$

Temperature $\sim 80^\circ\text{C}$

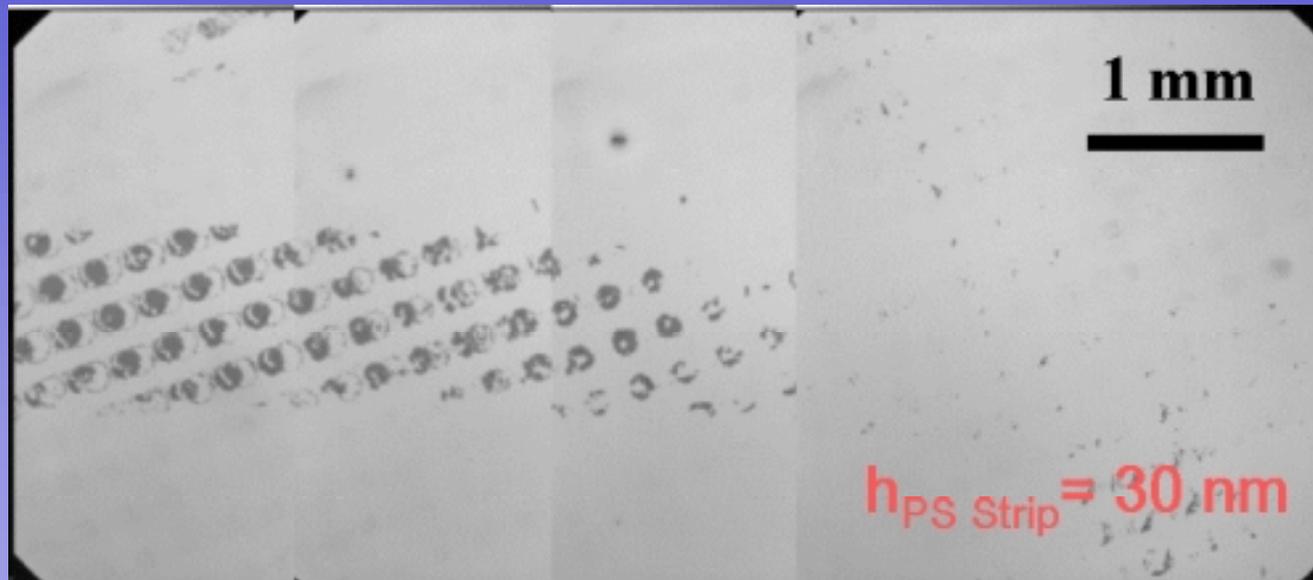
Library
Evaluation



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What is the critical temperature for PS welding?

Let's use combi!

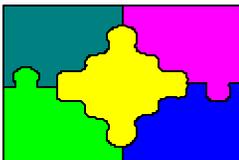


80°C

75°C

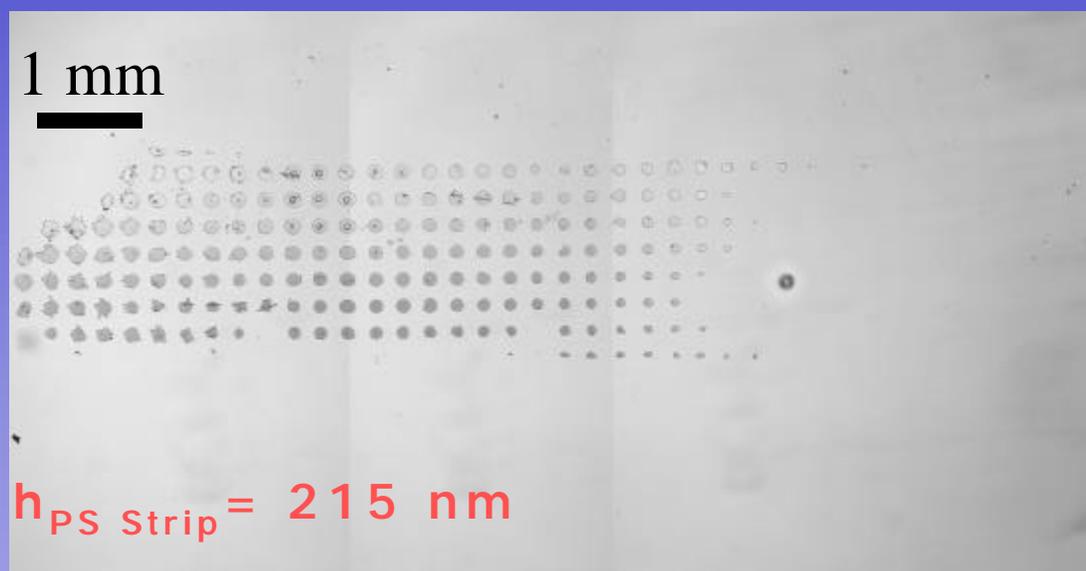
70°C

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Evaluation



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Does the critical temperature depend on thickness?



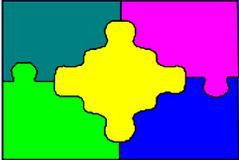
100°C

95°C

90°C

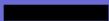
85°C

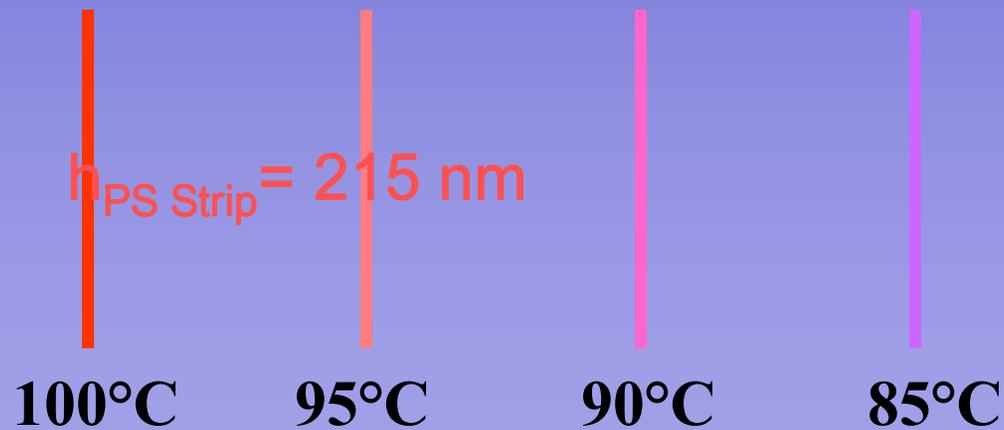


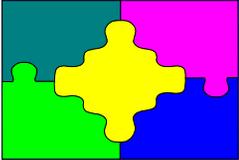


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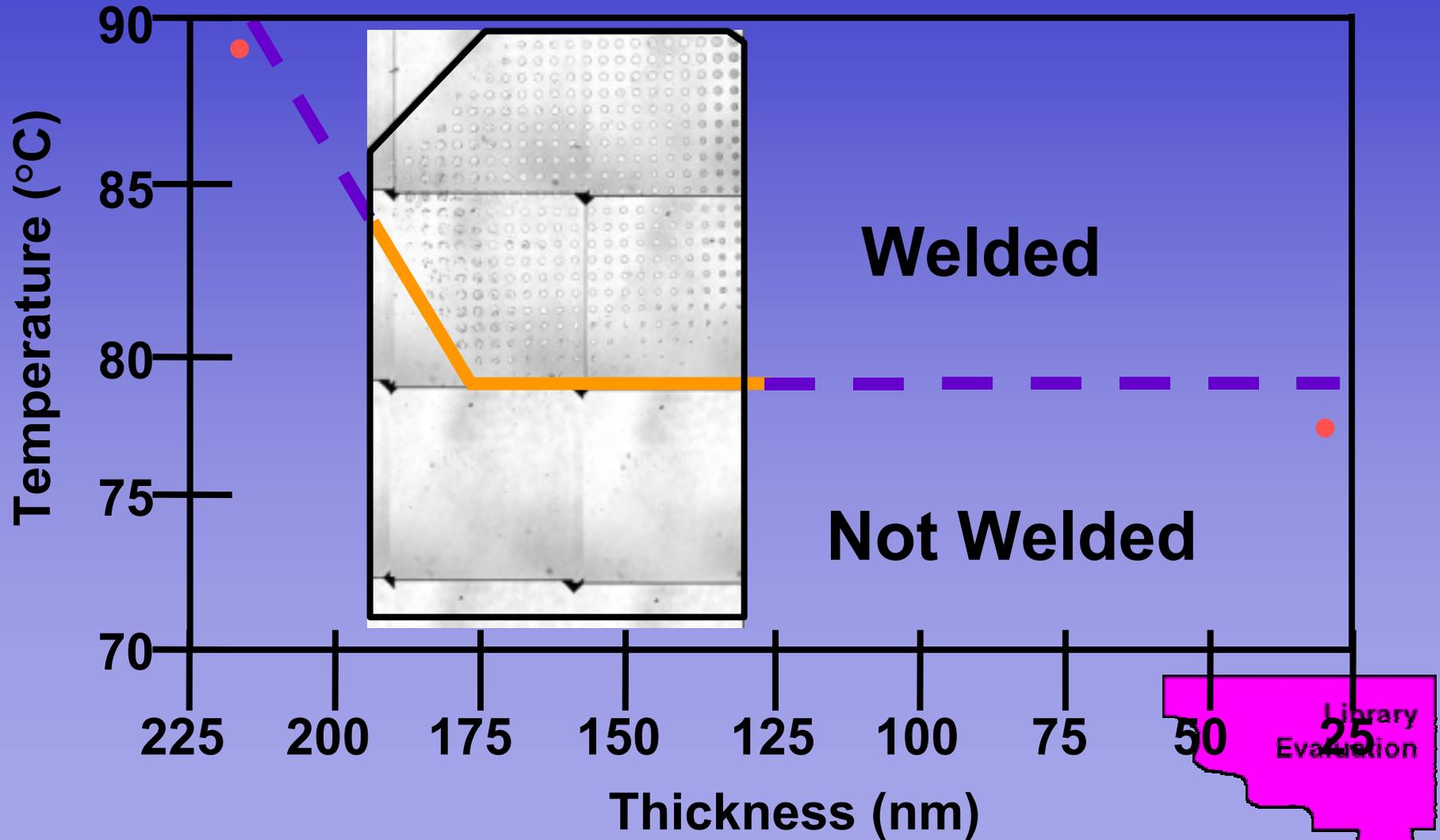
Does the critical temperature depend on thickness?

1 mm


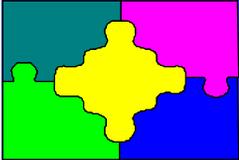




Does the critical temperature depend on thickness?



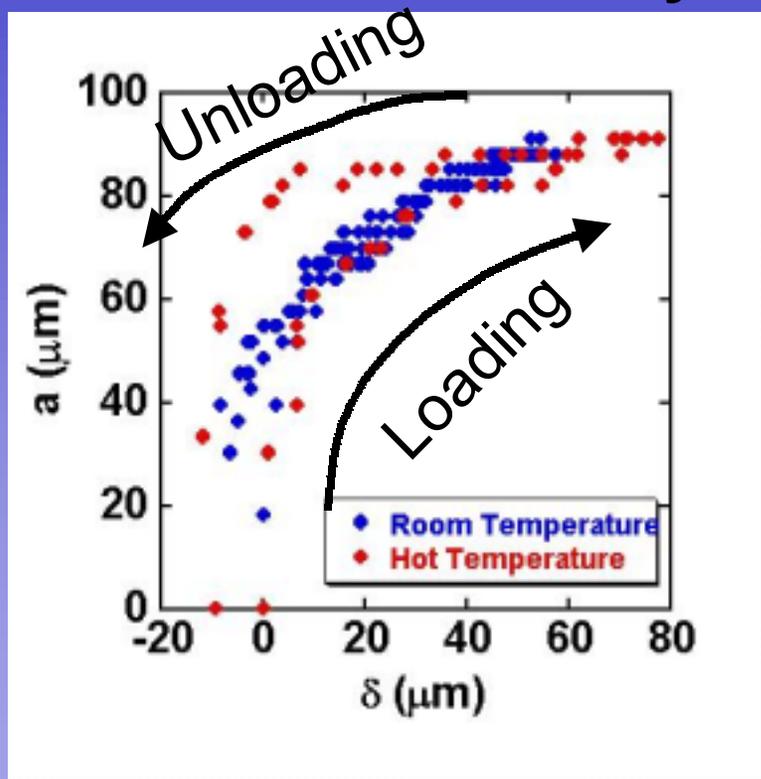
Library
Evaluation



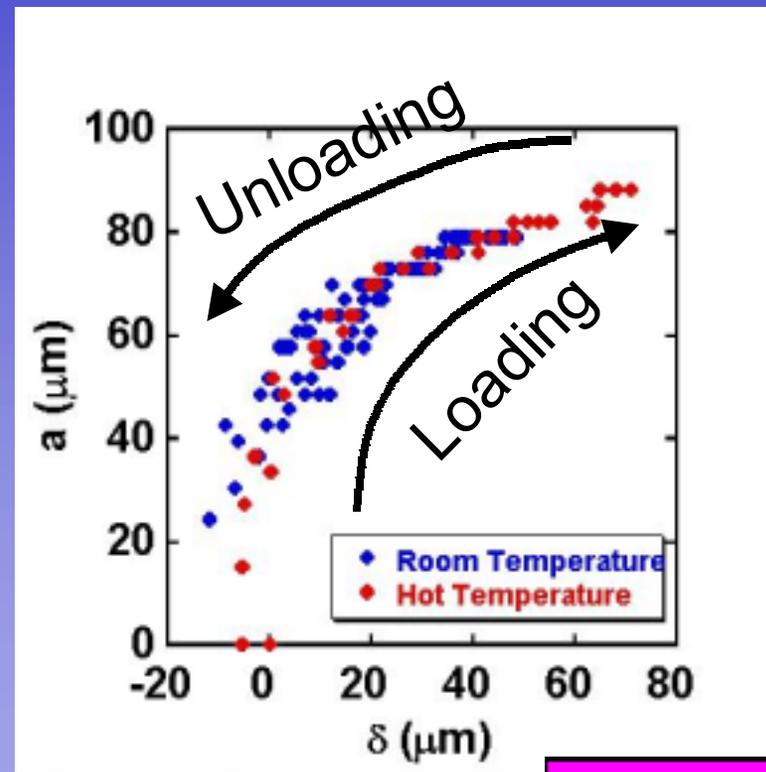
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What does the data look like?

PS/PS Contact History

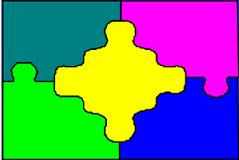


PS/PDMS Contact History



Same Sample, Same Conditions!

Library
Evaluation



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Automated Analysis

Combinatorial Adhesion Analysis

Directory Path for Input Files

c:\test\

Directory Path for Output Files

c:\test_out\

Path for Composite Image

c:\test_out\

Threshold Values

Minimum Value

Maximum Value



Number of Files

820

Time of First Image

550.183

Pixel Conversion

0.5971

E (Pa)

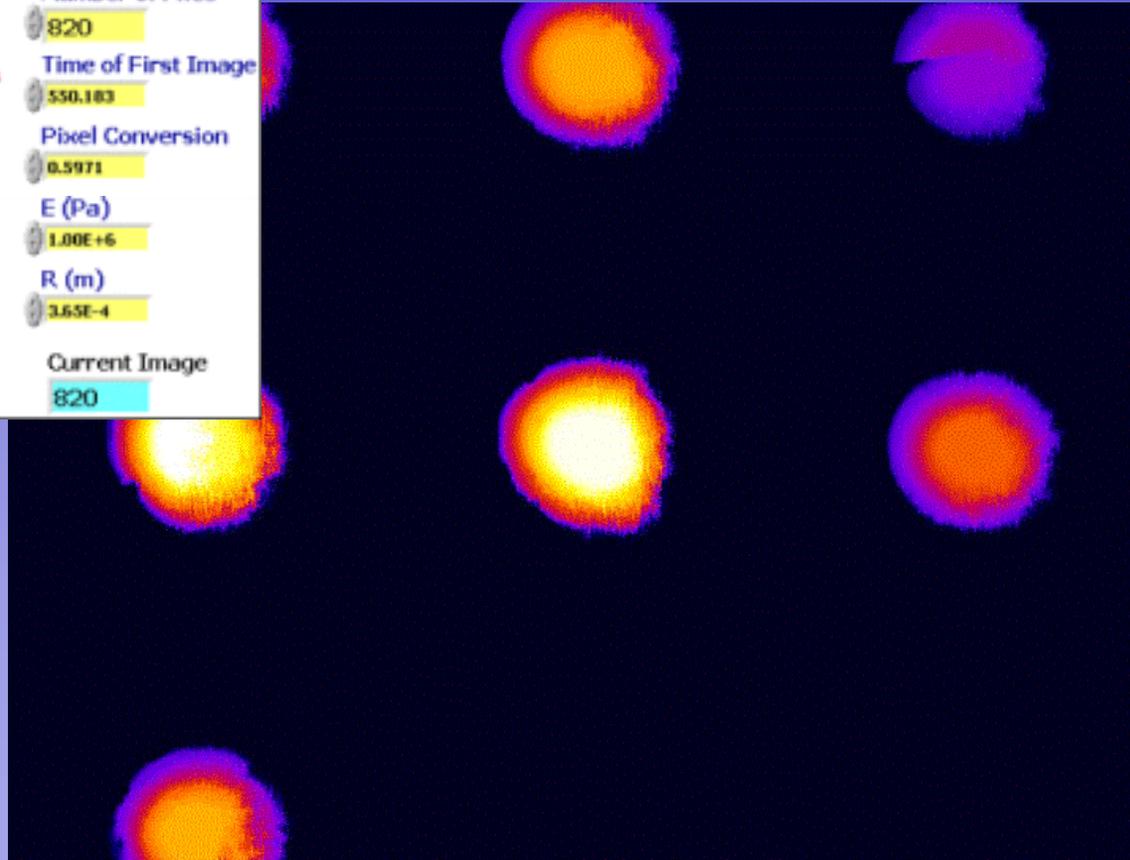
1.00E+6

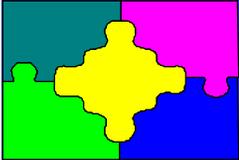
R (m)

3.65E-4

Current Image

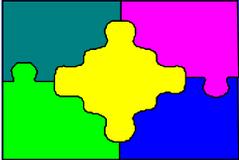
820





What are the main points?

- Multilens contact reflects classical JKR results
- Combinatorial methods are powerful for studying polymer adhesion
 - e.g. 1600 JKR tests within the time of one conventional test
- Thickness of glassy polymer affects welding temperature
- Adhesion maps provide quick assessment of interfacial properties



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Acknowledgements

- National Research Council Research Associateship Program
- Many helpful discussions with:
 - Ken Shull
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